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van Stralen, M.M.; de Vries, H.; Bolman, C.; Mudde, A.N.; Lechner, L.

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ORIGINAL ARTICLE

Exploring the Efficacy and Moderators of Two Computer-Tailored Physical Activity Interventions for Older Adults: A Randomized Controlled Trial

Maartje M. van Stralen, M.Sc. · Hein de Vries, Ph.D. · Catherine Bolman, Ph.D. · Aart N. Mudde, Ph.D. · Lilian Lechner, Ph.D.

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Abstract
Background Important health benefits can be derived when low-cost (e.g., computer-tailored) physical activity interventions for older adults demonstrate sustained effects.
Purpose The purpose of the study was to conduct in-depth analysis on the long-term efficacy of two tailored physical activity interventions for older adults.
Methods A randomized controlled trial (n=1,971) with two computer-tailored interventions and a no-intervention control group was conducted. The two tailored interventions consisted of three tailored letters, delivered during 4 months. The basic tailored intervention targeted psychosocial determinants alone, while the environmentally tailored intervention additionally targeted environmental determinants, by providing tailored environmental information. Self-reported behaviors (i.e., total physical activity, transport walking and cycling, leisure walking and cycling, and sports) were measured at baseline and 12 months. Additionally, potential personal, health-related, and psychosocial moderators of the intervention effects were examined.
Results The environmentally tailored intervention was effective in changing total physical activity, leisure cycling, and sports compared with the basic intervention and control group. No intervention effects were found for the basic intervention. Moderation analysis revealed that participants with a higher age, lower body mass index, and higher intention were unresponsive to the interventions.
Conclusions Providing environmental information is an effective intervention strategy for increasing physical activity behaviors among older adults, especially among certain "at-risk" subgroups such as lower educated, overweight, or insufficiently active participants. Moderation analysis was perceived as a promising method for identifying meaningful subgroups that are unaffected by an intervention, which should receive special attention in future interventions.

Keywords Physical activity · Intervention · Older adults · Moderators · Environment

M. M. van Stralen · C. Bolman · A. N. Mudde · L. Lechner
Department of Psychology, Open University of the Netherlands, Heerlen, The Netherlands

M. M. van Stralen (✉)
EMGO Institute for Health and Care Promotion,
VU University Medical Center,
Amsterdam, The Netherlands
e-mail: mm.vanstralen@vumc.nl

H. de Vries
Department of Health Promotion, Maastricht University,
Maastricht, The Netherlands

Introduction

Sufficient physical activity (PA) among older adults, defined as meeting the international recommendation of 30 min of moderate PA a day for at least 5 days of the week [1], lowers the risk of health problems that are particularly salient among older adults such as cardiovascular disease, obesity, osteoporosis, and type 2 diabetes [2, 3]. Despite these health benefits, in most Western countries, older adults are the most inactive part of the population. Important health benefits can be derived from low-cost (e.g., computer-tailored) interventions for older adults by promoting sufficient PA that demonstrates sustained effects. In order to improve the effectiveness of PA interventions among older adults, this paper conducted an in-depth analysis on the long-term effect of two computer-tailored physical activity interventions for older adults.

Computer-tailored interventions, in which computer technology adapts health information to the specific needs and characteristics of a person [4, 5], is a low-cost strategy that has the potential to reach a large population. Computer tailoring has shown promising effects in various health promotion programs [6, 7], and has shown promising effects among older adults [8–10]. Researchers have recently acknowledged the importance of a more ecological approach to PA promotion by addressing social and physical environmental determinants in addition to focusing solely on intrapersonal determinants [11–14]. Additionally, several observational studies gave indications that interventions aiming at achieving realistic perceptions of PA possibilities in the immediate environment of the target group might be important in changing PA behavior [15–17]. This paper addresses this recent development by targeting the relationship between the individual and their environment and examining the additional effect of adding environmental information to an intervention. In order to be able to examine the additional effect of adding environmental information to an intervention, two computer-tailored PA interventions targeted at the over 50s were developed [18]. Both interventions consisted of three personalized feedback letters for changing PA behavior. The intervention included several intervention strategies that targeted motivational (e.g., intention and self-efficacy), pre-motivational (e.g., awareness), and post-motivational (e.g., planning) determinants. One such intervention (the environmentally tailored intervention) additionally provided tailored environmental feedback by presenting detailed information about PA possibilities at home and in the neighborhood and providing access to a website including a forum and e-buddy system. In order to examine the efficacy of the two interventions, a three-arm randomized controlled trial was conducted in which the efficacy of both interventions was compared with each other and a no-intervention control group [18]. In an earlier study, the intervention providing tailored environmental feedback was found to be effective in changing total weekly days of PA on the short term [19] and total weekly minutes of PA on the long term (data not shown).

In addition to the long-term efficacy analysis, this paper aimed to provide a deeper insight into the efficacy of the interventions in two ways. First, this study aimed to examine which PA behaviors (e.g., transport activities and leisure activities) were influenced by environmental information. Therefore, the first goal of this study was to identify the long-term efficacy of an environmentally tailored PA intervention on different types of PA behavior compared with a basic tailored intervention and a no-intervention control group. Since the additional environmental feedback provided information on leisure walking, cycling, and sports opportunities in the participants' environments, it was hypothesized that differences between the two interventions were most likely to occur in these sub-behaviors.

Second, another way to conduct the in-depth long-term efficacy analysis was to provide further insight into possible moderators of the effects of the two intervention conditions. A moderator is a third variable that affects the strength of the relationship between a program and its outcome [20]. A moderator is equivalent to the statistical concept of interaction, with the intervention effect varying across levels of the moderator (Fig. 1). Analyzing moderators of intervention effects identified which subgroups responded to an intervention and which did not, resulting in informative recommendations for future intervention developers. For example, by identifying age as a moderator, information can be tailored to the age of the target population in future interventions. In doing so, an intervention can be developed that is effective among all age groups.

Several pre-test characteristics, such as demographic factors (e.g., age, gender, and education level), health-related factors (e.g., baseline PA level and BMI), and psychosocial factors (e.g., level of motivation and level of attitude) were identified as possible moderators of intervention effects [21]. Despite their importance, few intervention studies have analyzed moderators and examined whether intervention effects differed among subgroups [21, 22]. Therefore, the second goal of this paper was to identify the moderators of the two tailored PA interventions on total weekly minutes of PA behavior by examining whether the intervention effects of the two programs differed in the pre-test demographic, health-related, and psychosocial characteristics of the study population. Since we tailored the feedback on all the participants' demographic, health-related, and psychosocial factors, no significant moderated effects were expected.

Methods

The study was registered at the Dutch Trial Register (NTR920) and approved by the Medical Ethics Committee of Maastricht

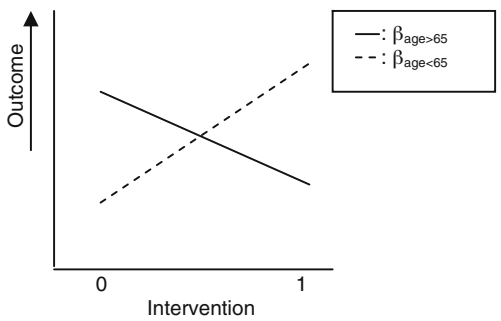

Fig. 1 Conceptual moderating framework

University and the University Hospital Maastricht. Participants were asked to complete a questionnaire at baseline and 3, 6, and 12 months (8 months post-intervention).

Participants and Procedure

The procedure of the study, including the selection and enrolment of participants and the distribution of the questionnaires and interventions, are shown in Fig. 2. A clustered randomized controlled trial was conducted that included three research arms: (1) basic tailored intervention, a motivational focused tailored intervention targeting psychosocial determinants; (2) environmentally tailored intervention, a motivational plus environmentally focused tailored intervention targeting environmental determinants in addition to the tailored feedback of the basic intervention; or (3) wait list control. In 2007, all Dutch Regional Municipal Health Councils (MHCs) (n=39) were invited to participate in the program. Nine MHCs agreed to participate, after which six MHCs were randomly selected and assigned to one of the three research arms. Randomization was stratified by urbanization level. Per MHC, depending on the size of the invited municipalities, one or two municipalities were invited to participate resulting in three municipalities per research condition. All invited municipalities were willing to participate. In total, a random sample of 8,500 adults aged 50 and over was selected and invited to participate to be able to include 2,000 participants. Based on a significance level of 0.05 and a power of 0.90, the minimum sample size of response of each research condition at 12 months should be 450 subjects, to detect a relative increase of 5% in PA behavior caused by the environmental information. The expectation of this small effect size was based on the results of previous studies [6, 7]. Although small, these changes are

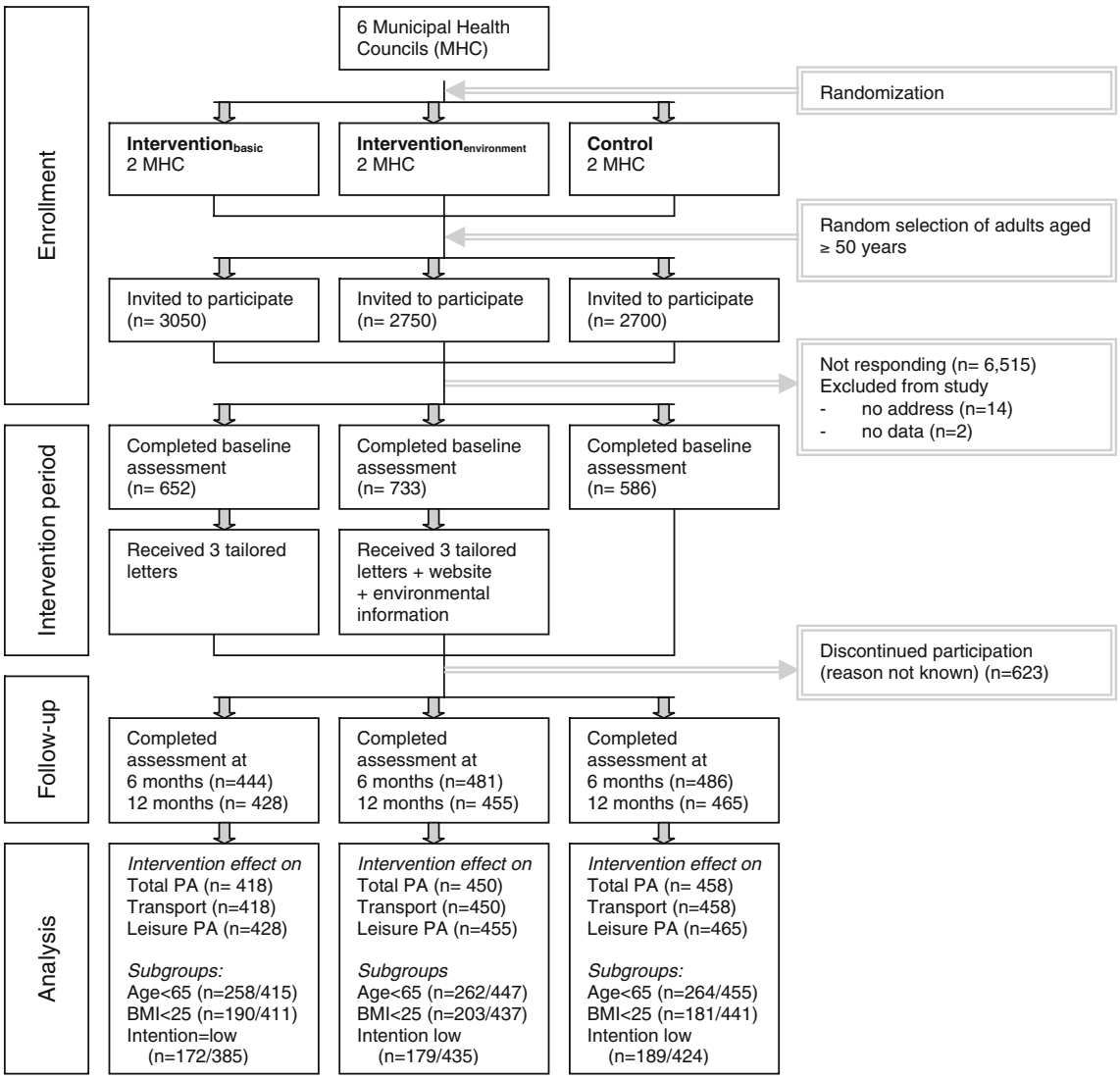

Fig. 2 Flow diagram of the study

meaningful. Since computer-tailoring facilitates the delivery of feedback to a large number of people, small changes among a large group can result in a considerable impact at the population level. Since a 30% dropout was expected between baseline and month 12, 2,000 participants were needed to be included at baseline. Participants were invited to participate by an invitation letter, which was accompanied by a baseline questionnaire and informed consent form. To encourage participation, participants were eligible to win city trips or gift vouchers. Baseline measurement lasted from March to June 2007.

Intervention and Design

Two theory and evidence-based interventions were systematically developed according to the Intervention Mapping protocol [23], which is a six-step protocol that facilitates a stepwise process for theory- and evidence-based development of health promotion interventions. The determinants on which the programs focused were selected based on the results of a Delphi study [24], and a literature review [14] on the determinants of changing PA behavior among older adults. Based on theoretical models such as the such as the I-Change model [25], the Transtheoretical model [26], the Health Action Process Approach [27], the Precaution Adoption Process Model [28], the Self-regulation theory [29], and the Self-determination theory [30] and on additional focus group interviews [18], theoretical methods and intervention strategies were selected and included into the computer-tailoring program. The content of the tailored interventions has been described in more detail elsewhere [18], and is briefly described below. Print-delivered computer-tailored interventions were found to be more effective in changing PA maintenance than telephone-tailored interventions [31] especially among older adults [32]. Therefore, two computer-tailored interventions, including written letters, were developed. Web-based tailoring has advantages when compared to print-based tailoring in that it allows more interactivity, and the possibility of reaching a larger population at lower costs [33]. However, the study sample described in this thesis comprised older adults who were, especially the elderly older adults, expected to be less comfortable with the use of the computer. In order to able to reach a population as diverse as possible, including the elder older adults, it was decided to use written questionnaires and written letters to gather data and provide tailored feedback.

Basic tailored intervention participants (n=654) received three tailored letters including personalized PA advice. The intervention tried to influence PA behavior by targeting several psychosocial determinants that underlie PA behavior change (e.g., awareness, attitude, social influence, self-efficacy, intention, and self-regulation skills). The first and second tailored letters were based on personal data gathered at baseline and were sent 2 weeks and 2 months after baseline, respectively. The third letter was sent 2 weeks after receiving the 3-month questionnaire and was based on the data gathered at baseline and 3 months, and addressed any changes in determinants and PA each older adult had undertaken during these 3 months. The letters comprised between three and 11 pages depending on (changes in) PA level and determinant scores.

Environmentally tailored intervention participants (n=737) received the same tailored information as the basic tailored intervention participants but additionally received tailored information about PA opportunities in their specific environment. The environmental information comprised handouts on walking and cycling routes in their neighborhood, examples of exercises to do at home, and contact information for local sports clubs matching their interests and abilities combined with access to a forum and e-buddy system on a website to increase social and environmental determinants.

Waiting list control participants (n=586) received nothing during the intervention period. After the last post-test, at 12 months, they received one tailored letter, which was a combination of the three tailored letters from the basic intervention.

In an earlier process evaluation study, we had found that among the intervention participants, 98% had read the tailored letters, 68% saved the letters, and 37% discussed the letters with others [19].

Questionnaires

Outcome Measures

The primary outcome measures were taken at baseline and 12 months and included weekly minutes of total PA behavior, weekly minutes of two transport activities (i.e., walking and cycling), and weekly minutes of five leisure activities (i.e., walking, cycling, gardening, doing odd jobs, and sports). The outcomes were assessed using the validated self-administrated Dutch short questionnaire to assess health enhancing physical activity (SQUASH). The reproducibility ($r_{Spearman}$=0.58; 95% CI=0.36–0.74) and relative validity ($r_{Spearman}$=0.45; 95% CI=0.17–0.66) of the SQUASH are reasonable [34, 35]. The total number of minutes per activity was calculated by multiplying the frequency of the activity (how many days per week) by the duration of the activity, regardless of the intensity of the activity. Total weekly minutes of PA were calculated by summing the individual activity scores.

Moderators

Based on an earlier moderation analysis of the intervention effect on PA behavior of older adults [36], the following (1)

demographic, (2) health related, and (3) psychosocial characteristics of participants (assessed at baseline) were selected as potential moderators of the intervention effect.

1. Demographic characteristics

Age, gender, highest completed educational level, and having a partner were assessed. A mean-split classification (mean=64 years, SD=8.6) was completed for age to assign participants to either the low (aged<65) or the high (aged≥65) age group. Educational level was dichotomized into "low" (elementary education, medium general secondary education, preparatory vocational school, or lower vocational school) and "medium/high" (higher general secondary education, preparatory academic education, medium vocational school, higher vocational school, or university level).

2. Health-related characteristics

Participants' height, weight, functional limitations, and compliance with the guidelines were measured as potential health-related moderators. Participants self-reported weight and height were used to compute body mass index (BMI), followed by a mean-split classification (mean BMI=25.4, SD=3.8) to assign participants to either the "low" (BMI< 25, n=837) or "high" (BMI≥25, n=1,073) BMI groups. Functional limitations were measured using a single-item question in which participants indicated whether they had physical complaints that limited their PA behavior (no (0) or yes (1)). Compliance with the PA guidelines at baseline was derived from a single item question of the SQUASH [35]: "How many days per week are you, in total, at least moderately physically active, such as heavy walking, cycling, odd jobs, gardening, sports or other physical activities for at least 30 min." Scores were dichotomized into being sufficiently physically active for fewer than 5 days per week (0) or 5 or more days per week (1).

3. Psychosocial characteristics

Attitude, social support, self-efficacy, and intention to be physically active were assessed as potential psychosocial moderators of the intervention effect. Attitudes toward PA were assessed using pros and cons derived from focus group interviews with the target population [18] and an earlier study on PA [37]. The pros of PA were assessed by nine items (e.g., "I find being regularly physically active very enjoyable"), and the cons of PA were assessed by seven items (e.g., "I find being regularly physical active very time consuming") using a five-point Likert scale (totally disagree (−2) to totally agree (+2)). Cons were then recoded, after which mean scores were calculated; Cronbach's α was 0.86 for pros items and 0.77 for cons items. Social support was derived from an earlier study on PA [37] and consisted of a single item question asking to what degree people in their direct environment supported them to be sufficiently physically active using a four-point Likert scale (no support (1) to much support (4)). Self-efficacy was measured using a 10-item scale derived from the validated self-efficacy for exercise scale [38] and focus group interviews with the target population [18], in which participants rated their confidence in being able to be regularly physically active when faced with common barriers using a five-point Likert scale (definitely (or certainly) unable (−2) to definitely able (+2)). Mean scores were calculated; Cronbach's α was 0.93. Intention to be physically active was derived from an earlier study [39] and was assessed by three items (e.g., "are you planning to be sufficiently physically active?") using a 10-point Likert scale ("absolutely no" (1) to "absolutely yes" (10)). Mean scores were calculated; Cronbach's α was 0.76. All psychosocial variables were analyzed as continuous variables and categorized using the mean-split classification.

Statistical Analyses

One-way analyses of variance were conducted to test for baseline differences in participant demographics (moderators) and PA levels among the three conditions. Further analyses corrected for possible differences. Logistic regression analyses were conducted to examine if dropout was associated with baseline characteristics. Analyses were performed using SPSS for Windows (version 15.0).

Participants were nested in districts within their municipality using the probability of interdependence between them. To account for this interdependence, multilevel linear and logistic regression analyses with a random intercept for two levels (living district (2) and individual (1)) were completed to analyze the efficacy and moderation effects using MLWin (version 2.02). Analyses were applied to the total dataset, including missing data, to account for possible selective dropout. Multilevel analyses are useful for handling missing data. Moreover, applying multilevel analyses to an incomplete dataset has been shown to give more accurate estimations than applying imputation methods [40].

Linear regression analyses were performed to assess intervention effects and compare their differences between the two interventions. Each 12-month outcome measure (i.e., total weekly minutes of PA, transport cycling, transport walking, leisure cycling, leisure walking, gardening, doing odd jobs, and sports) was regressed against its baseline value, two intervention dummies ($\text{Dummy}_{I_{\text{basic}}}$, $\text{Dummy}_{I_{\text{environment}}}$, control group as reference) and covariates.

Analyses of moderation effects were undertaken by including a two-way interaction term (i.e., $\text{Dummy}_{I_{\text{basic}}} \times$

moderator; Dummy$_{I_{environment}}$ × moderator) in each of the aforementioned regression analyses [41], followed by stratification of the data, preconditioned by significance of the interaction term, by the levels of the moderator and by re-examining the intervention effects. Since interaction terms have less power, p values, as an indicator of the significance, of interaction terms are recommended to be set at 0.10 [42].

In all analyses, the changes in outcomes in the intervention condition were compared with the control condition. In regression analyses, age, gender, educational level, BMI, having a partner, and having functional limitations were included as covariates because of their known influence on PA [14, 43].

Results

Baseline Characteristics

At baseline, 1,971 older adults completed the questionnaire (response rate 23%), while 1,348 completed the 12-month questionnaire (68% response rate). Dropout analyses showed that participants who did not have a partner (odds ratio (OR)=1.32; 95% CI=1.16–1.51), or participants who were randomized in one of the intervention conditions ($OR_{I_{basic}} = 2.09$; 95% CI=1.81–2.40; $OR_{I_{environment}} = 2.48$; 95% CI=2.17–2.83) were more likely to drop out at 12 months. Multilevel analyses using the total dataset including missing data accounts for the selective dropout.

The baseline characteristics are shown in Table 1. The three research conditions were found to differ for education, BMI, and self-efficacy. In the basic tailored intervention condition (51%) and control condition (50%), significantly more participants had a lower education compared with the environmentally tailored intervention (42%; $F(2, 1{,}928)=5.0$; $p<0.01$). Significantly more participants in the control condition (61%) had a BMI of 25 or higher compared with the participants of the basic intervention condition (53%; $F(2, 1{,}907)=4.3$; $p<0.05$). Participants in the basic tailored intervention group (mean=0.62, SD=0.67) had a significantly higher self-efficacy compared with participants in the control condition (mean=0.51, SD=0.71; $F(2, 1{,}744)=3.3$; $p<0.05$).

At baseline, participants were physically active for on average 634.9 (SD=451.9) min/week (Table 2). With regard to PA for transportation, participants walked on average 11.9 (SD=48.3) min/week and cycled on average 31.6 (SD=82.7) min/week. Regarding leisure PA, participants walked on average 164.0 (SD=192.3) min/week, cycled on average 135.7 (SD=182.7) min/week, played sports for an average of 110.8 (SD=155.1) min/week, and were active doing gardening for 103.9 (SD=165.9) min/week and odd jobs for 76.6 (SD=166.4) min/week. Significant baseline differences between the intervention conditions were found regarding cycling for transport ($F(2, 1{,}965)=6.6$; $p<0.01$), leisure walking ($F(2, 1{,}965)=3.5$; $p<0.05$), and leisure cycling ($F(2, 1{,}965)=3.3$; $p<0.05$) (Table 2). By regressing each outcome to its baseline value and including demographic variables as covariates, the analyses were corrected for baseline differences.

Intervention Effects on PA Behaviors

A significant intervention effect was found for the environmentally tailored intervention, in which the participants in

Table 1 Participant characteristics at baseline

	Total	Baseline characteristics		
		Control	Intervention$_{basic}$	Intervention$_{environment}$
Demographic factors (%)				
Age (≥65)	40	42	39	41
Gender (female)	57	57	58	55
Education (low)	48	52	52	42[a]
Marital status (partner)	81	82	81	79
Health- related factors (%)				
BMI (≥25)	56	61[b]	53	55
Physical limitations	30	31	30	30
Compliance guideline	51	49	50	53
Psychosocial factors (mean (SD))				
Self-efficacy	0.56 (0.68)	0.51 (0.67)	0.62 (0.71)[c]	0.56 (0.67)
Social support	2.1 (1.1)	2.1 (1.1)	2.1 (1.1)	2.1 (1.1)
Attitude	1.0 (.4)	1.0 (.4)	1.0 (.4)	1.0 (.5)
Intention	7.7 (1.8)	7.6 (1.8)	7.7 (1.9)	7.8 (1.8)

[a] Significantly less participants with low education in the environmentally tailored intervention condition compared with control and basic intervention condition ($F(2, 1{,}928)=5.0$; $p<0.01$)

[b] Significantly more participants with high BMI in the control condition compared with basic intervention ($F(2, 1{,}907)=4.3$; $p<0.05$)

[c] Significantly higher self-efficacy among participants in basic intervention compared with control condition ($F(2, 1{,}744)=3.3$; $p<0.05$)

Table 2 Physical activity behavior at baseline and 12 months and intervention effects on total physical activity, physical activity for transport, and leisure physical activity at 12 months

	Baseline measurement (mean (SD))			12 months measurement (mean (SD))			Intervention effect (β (95% CI))		
	C	I_{basic}	$I_{environment}$	*C*	I_{basic}	$I_{environment}$	I_{basic} vs. *C*	$I_{environment}$ vs. *C*	$I_{environment}$ vs. I_{basic}
Total PA (min/week)	610.4 (438.2)	662.8 (474.6)	629.8 (440.9)	620.0 (448.0)	670.7 (435.9)	703.2 (443.3)	13.5 (−42.4; 69.4)	62.0 (7.4; 116.6)[a]	48.5 (−6.3; 103.3)
Transport PA									
Walking	14.8 (53.5)	10.6 (46.1)	10.8 (45.8)	13.6 (45.9)	14.0 (49.3)	11.9 (44.7)	−0.4 (−7.1; 6.4)	−2.7 (−9.3; 3.9)	−2.3 (−8.9; 4.4)
Cycling	23.6 (69.3)	29.6 (81.9)	39.8 (92.0)[b]	23.9 (66.4)	32.7 (76.9)	44.9 (92.1)	4.0 (−5.3; 13.2)	6.4 (−2.6; 15.5)	2.5 (−6.7; 11.6)
Leisure PA									
Walking	149.9 (181.8)	178.6 (206.6)[a]	162.2 (186.5)	147.4 (168.0)	173.3 (187.1)	183.1 (203.8)	5.9 (−15.6; 27.4)	21.9 (1.0; 42.9)[a]	16.0 (−5.3; 37.4)
Cycling	123.9 (167.1)	149.8 (200.0)[a]	132.6 (177.7)	124.1 (175.9)	151.2 (192.1)	155.1 (188.3)	8.0 (−14.3; 30.3)	26.5 (4.8; 48.2)[a]	18.6 (−3.4; 40.5)
Sports	102.9 (145.8)	109.7 (158.6)	118.2 (158.9)	113.7 (144.3)	104.2 (148.9)	121.8 (155.2)	−13.6 (−30.3; 3.2)	0.7 (−15.7; 17.1)	14.3 (−2.2; 30.7)
Gardening	111.2 (176.6)	110.3 (172.8)	92.6 (149.8)	115.6 (184.8)	111.1 (167.6)	101.7 (157.7)	4.7 (−15.2; 24.6)	−2.3 (−21.8; 17.2)	−7.0 (−26.5; 12.5)
Odd jobs	84.1 (174.4)	73.8 (161.6)	73.2 (164.1)	75.6 (169.4)	71.6 (161.1)	77.2 (174.5)	5.5 (−14.8; 25.7)	7.2 (−12.6; 27.0)	1.8 (−18.3; 21.9)

Regression models were adjusted for age, gender, educational status, occupational status, having physical limitations, BMI, baseline PA level, and within-district clustering effects

PA physical activity, *C* control group, I_{basic} basic tailored intervention group, $I_{environment}$ environmentally tailored intervention, I_{basic} *vs. C* effect basic tailored intervention compared with control, $I_{environment}$ *vs. C* effect environmentally tailored intervention compared with control, $I_{environment}$ *vs.* I_{basic} effect environmentally tailored intervention compared with basic tailored intervention

[a] Significantly different from control group ($p<0.05$)

[b] Significantly different from control group ($p<0.01$)

the environmentally tailored intervention increased their total weekly minutes of PA by 1 h/week more ($\beta_{I_{\mathrm{environment}}}=62.0$; 95% CI=7.4–116.6; $p<0.05$) compared with the control condition (Table 2). This significant intervention effect on total PA behavior could mainly be assigned to a significant intervention effect on weekly minutes of leisure walking ($\beta_{I_{\mathrm{environment}}}=21.9$; 95% CI=1.0–42.9; $p<0.05$) and leisure cycling ($\beta_{I_{\mathrm{environment}}}=26.5$; 95% CI=4.8–48.2, $p<0.05$). No significant intervention effects were found for the basic intervention condition compared with the control group in weekly minutes per week of total PA or sub-behaviors.

Differences in Intervention Effects

As shown in Table 2 (last column), borderline significant differences in intervention effects were found between the environmentally tailored intervention and basic tailored intervention conditions for weekly minutes of total PA. Participants in the environmentally tailored intervention increased their PA behavior by almost 50 min/week more than participants in the basic intervention ($\beta_{I_{\mathrm{environment}}\mathrm{vs.}I_{\mathrm{basic}}}=48.5$; 95% CI=–6.3–103.3; $p=0.08$). These differences in intervention effects could mainly be assigned to borderline significant differences in weekly minutes of leisure cycling ($\beta_{I_{\mathrm{environment}}\mathrm{vs.}I_{\mathrm{basic}}}=18.6$; 95% CI=–3.4–40.5; $p=0.09$) and participation in sports ($\beta_{I_{\mathrm{environment}}\mathrm{vs.}I_{\mathrm{basic}}}=14.3$; 95% CI=–2.2–30.7; $p=0.09$), in which the participants of the environmentally tailored intervention group increased their activities in leisure cycling and sports more than basic intervention participants.

Moderation Analyses

Moderation analyses were conducted on the effects of both interventions on changes in weekly minutes of total PA compared with the control condition.

Demographic Moderators

Significant interaction effects were found for age, which significantly moderated the intervention effect of the basic tailored intervention compared with the control condition on total weekly minutes of PA ($\beta_{I_{\mathrm{basic}\times\mathrm{age}}}=-92.2$; SD=52.8; $p=0.08$). Subgroup analyses (Table 3) showed that both interventions were ineffective in changing total PA behavior among the elder older adults (aged 65 and older), while the environmentally tailored intervention was effective among the younger aged participants (aged 64 and younger). No significant interaction effects were found for other demographic factors indicating that the environmentally tailored intervention was as effective (and the basic intervention as ineffective) for both male and female; lower,

Table 3 Total weekly minutes of physical activity behavior at baseline and 12 months and intervention effects on total weekly minutes of physical activity for subgroups

	Baseline measurement (mean (SD))			12 months measurement (mean (SD))			Intervention effect (β (95% CI))	
	C	I_{basic}	$I_{\text{environment}}$	*C*	I_{basic}	$I_{\text{environment}}$	I_{basic} vs. *C*	$I_{\text{environment}}$ vs. *C*
Age								
<65 years	591.7 (408.7)	646.7 (441.3)	620.5 (424.8)	588.4 (376.0)	695.4 (428.3)	678.6 (406.3)	53.7 (−18.9; 126.4)	76.5 (4.9; 148.0)[a]
≥65 years	637.5 (477.8)	684.4 (518.3)	642.2 (466.9)	661.1 (531.1)	627.5 (448.6)	740.3 (492.6)	−46.9 (−135.9; 41.9)	43.3 (−42.2; 128.8)
BMI								
<25 kg/m²	591.8 (392.5)	699.2 (480.6)	637.3 (436.6)	637.9 (456.7)	751.9 (443.7)	701.1 (416.8)	−6.4 (−90.6; 77.7)	1.49 (−80.8; 83.8)
≥25 kg/m²	618.7 (457.8)	636.9 (465.8)	631.2 (444.5)	596.9 (426.0)	603.4 (418.7)	710.2 (459.0)	28.2 (−39.0; 95.4)	108.2 (42.3; 174.1)[b]
Intention								
Low (<7.7/10)	556.0 (461.8)	546.6 (455.2)	514.5 (394.8)	530.2 (443.0)	584.9 (431.5)	623.8 (411.9)	63.4 (−13.2; 139.9)	118.7 (43.3; 194.2)[b]
High (≥7.7/10)	692.2 (407.7)	761.8 (451.5)	741.8 (447.5)	708.5 (443.5)	760.8 (413.4)	775.3 (457.1)	−17.2 (99.9; 65.6)	20.1 (−59.3; 99.5)

Regression models were adjusted for age, gender, educational status, occupational status, having physical limitations, BMI, baseline PA level, and within-district clustering effects

PA physical activity, *C* control group, I_{basic} basic tailored intervention group, $I_{environment}$ environmentally tailored intervention group, I_{basic} *vs. C* effect basic tailored intervention compared with control, $I_{environment}$ *vs. C* effect environmentally tailored intervention compared with control

[a] Significantly different from control group $p<0.05$

[b] Significantly different from control group $p<0.01$

middle, and higher educated; and single and married participants.

Health-Related Moderators

Significant interaction effects were found between BMI and the intervention effect of the environmentally tailored intervention on total weekly minutes of PA ($\beta_{I_{\text{environment}\times\text{BMI}}}=106.2$; SD=50.0; $p<0.05$). Table 3 shows that both interventions were ineffective in changing PA behavior among non-overweight participants (BMI<25), whereas the environmentally tailored intervention was highly effective among overweight participants. No significant interaction effects were found for the other potential health-related moderators, indicating that the effectiveness of the intervention was as similar for participants with and without physical limitations as for participants complying and not complying with the PA guidelines. This latter finding assumes that the environmentally tailored intervention was effective in stimulating PA initiation among insufficiently active participants and in stimulating PA maintenance among sufficiently active participants.

Psychosocial Moderators

Significant interaction effects were found between intention and the intervention effect of both the basic intervention ($\beta_{I_{\text{basic}\times\text{intention}}} = -83.9$; SD=50.0; $p=0.09$) and the environmentally tailored intervention ($\beta_{I_{\text{environment}\times\text{intention}}}=106.0$; SD=50.5; $p<0.05$) on total weekly minutes of PA. Subgroup analyses (Table 3) showed that compared with the control condition both interventions were ineffective in changing total PA behavior among participants with a high intention (scores of 7.7 or higher on the 10-point scale), whereas only the environmentally tailored intervention was highly effective in changing PA behavior among the participants that were less motivated. This indicates that the environmentally tailored intervention was effective among the at-risk subgroup of participants (i.e., low motivation to change behavior). No significant interaction effects were found for the other potential psychosocial moderators, indicating that the effectiveness of the interventions was similar among participants with high or low social support, a positive or less positive attitude, and a high or low self-efficacy.

Discussion

This study aimed to conduct an in-depth analysis of the long-term efficacy of an environmentally tailored intervention compared with a basic tailored intervention and no-intervention control group in two ways. Firstly, it was aimed

to identify which sub-behaviors were influenced by the provided environmental information. Secondly, it was aimed to identify subgroups that were responsive or unresponsive to the two computer-tailored interventions. The results allow three conclusions to be drawn.

First, the basic intervention solely targeting psychosocial determinants was ineffective in changing total weekly minutes of PA behavior or any of the sub-behaviors among older adults compared with the control condition. Although the basic intervention, tailored to psychosocial determinants alone, was in earlier studies found to be effective in changing weekly days of PA behavior among older adults in the short [19] and long term (data not shown), it was ineffective in changing total weekly minutes of PA. This suggests that different measures of PA (e.g., weekly minutes vs. days of PA) comprise different reflections of total PA behavior, which can result in different intervention effects. This could be attributed to the cut-off points used in the definition of weekly days of physical activity behavior (i.e., the amount of days which the participant is at least moderately physically active for at least 30 min). It is possible that a minor non-significant change in weekly minutes of PA was enough to make a significant change in weekly days of PA. Since both measures have their advantages and disadvantages, we recommend future intervention studies to present both outcomes. Our results, however, do imply that targeting psychosocial concepts alone does not result in a long-term change in minutes of PA behavior.

The environmentally tailored intervention on the other hand was found to be effective in changing total weekly days [19] and total weekly minutes of PA behavior, leisure walking, and leisure cycling compared with the control condition. These findings are important considering the need for effective PA promotion interventions among this age group. The effect size found for the environmentally tailored intervention on total PA was small (ES=0.19, not presented in results). To our knowledge, only one other study assessed the sustained effects of a print tailored PA intervention among older adults [44], but could not find significant effects on self-reported PA behavior. Yet, our results are consistent with the findings of studies analyzing the long-term efficacy of (tailored) PA telephone counseling among older adults to increase minutes of PA per week [45, 46]. The environmentally tailored intervention was found to be more effective in changing total PA behavior, cycling, and sports than the basic tailored intervention. This indicates that providing older adults with environmental information results in more minutes per week of total PA, cycling, and sports behavior. This is largely in agreement with our hypothesis. The environmental information provided by the intervention targeted mainly leisure walking, cycling, and sports behavior by offering information on walking, cycling, and sports possibilities in the participants' local environment. It is therefore likely that the intervention with environmental information was more effective in inducing change in these specific behaviors than the intervention without environmental information.

The environmental information we provided were low-cost intervention materials that were easily obtained. To specify, the provided environmental information comprised handouts on existing walking and cycling routes in their neighborhood, examples of exercises to do at home, and contact information for local sports clubs that matched the interests and needs of the participant. In addition, they had access to a forum and e-buddy system on a website, to find a local buddy for exercising together. Since the environmentally tailored intervention program was effective in changing weekly minutes and days of PA behavior on the long term, targeting environmental determinants in a PA intervention provides an effective way of stimulating PA among older adults. This assumption could be underpinned by our earlier process evaluation [47], in which we found that the environmentally tailored intervention participants perceived their letters as more interesting, inviting, and individualized and as less irritating than the basic tailored intervention participants. Hence, future interventions promoting PA on the individual level are recommended to include environmental information to their intervention program. However, it must be noted that although 41% of the participants walked or cycled one or more of the provided existing walking or cycling trials, the use of the other environmental information features was low. Future intervention research should therefore seek for other, more powerful, intervention strategies to provide environmental information. To conclude, although adding environmental information to an intervention looks promising, based on the modest results in changing PA and the low use of some of the environmental information materials, we believe that the environmental component can be strengthened. To our knowledge, this study is the first to indicate the additional long-term effect of targeting environmental determinants in addition to psychosocial determinants.

Second, several effect modifiers of the intervention effects were identified, specifying which subgroups were and which were not affected by the intervention. The basic tailored intervention was ineffective among the total study population and among all subgroups. With regard to the environmentally tailored intervention, although an intervention effect on weekly minutes of PA behavior was found for the overall study population compared to both the control and basic intervention groups, there were certain subgroups that remained unaffected by the interventions. In this study, participants with a higher age, lower BMI, and higher intention were found to be unaffected by environmentally tailored intervention. The ineffectiveness of the interventions among the older subgroup is in agreement

with the study of Wilcox et al. [36], who found that the intervention effect of a telephone- and group-based intervention among older adults was more effective among the younger participants (aged 50–64). In addition, King et al. found among 269 older adults aged 50–65 years that older participants were less likely to adhere to a 2-year exercise program [48]. This lower effectiveness could be explained by the fact that older participants could have more (acute) health problems or life events during the intervention, resulting in a decrease in compliance [36]. The lack of intervention effect among participants with a higher intention are in line with the findings of study of Greaney et al. on the long-term effectiveness of a print tailored PA intervention among 966 older adults [44]. The authors could not find an intervention effect on total PA behavior among the total study population, but found that the intervention was more effective among a subgroup of participants who were not considering becoming physically active (precontemplators). Subgroups with a higher age, lower BMI, and higher intention that were unaffected by the interventions are of concern and should be the focus in future intervention studies. Although the current study did tailor the provided feedback on age, BMI, and intention of the participants, the extensiveness of tailoring could have been insufficient. For future intervention development, tailoring the information on different subgroups, especially the less responsive subgroups (i.e., high age, low BMI, and high intention), is recommended.

In addition, identification of subgroups that were responsive to the environmentally tailored intervention is also important. Significant intervention effects of the environmentally tailored intervention were found among participants with lower age, higher BMI, and lower intention to be physically active. In addition, significant intervention effects were also found among the participants irrespective of their gender, educational level, partner status, functional limitations, baseline PA level, attitude, social support, and self-efficacy. The results of the study are promising since participants more at risk (e.g., lower educated, higher BMI, having functional limitations, being insufficiently active, being less motivated or having lower social support, self-efficacy, or attitude) are often less responsive to an intervention and are less likely to change their PA behavior [14, 22]. In this study, however, the more at-risk subgroups increased their PA behavior equally or sometimes even more than their less at-risk counterparts as a result of the environmentally tailored intervention. Especially, the non-significant moderated effect of baseline PA level is an important finding, since it indicates that the intervention was effective in inducing PA initiation among the at-risk insufficiently active participants as well as in inducing PA maintenance among "less at risk" sufficiently active participants. This could have important public health implications, if confirmed by subsequent studies, considering that the participants at risk could benefit from a low-cost intervention program.

The lack of moderation of personal characteristics confirms the results of a recent study by Lorentzen et al., who found that none of their measured personal characteristics (i.e., gender, age, ethnicity, education, or BMI) moderated the effect of a 3-year community-based intervention on PA behavior among the general adult population [49]. However, the lack of moderation of health-related characteristics (i.e., functional limitations and baseline PA level) do not confirm the findings of the study of Wilcox et al. who found that their two interventions were more efficient among participants less active at baseline [36]. Since our interventions were developed in such a way that they stimulated PA initiation among insufficiently active participants and PA maintenance among sufficiently active participants, our findings are in line with our expectations. Finally, the lack of moderation effect for the remaining psychosocial characteristics (i.e., attitude, social support, and self-efficacy) is encouraging and may be attributed to the tailored intervention content. All participants received tailored feedback based on their stage of change and background characteristics. For instance, participants with a somewhat negative attitude toward PA received tailored attitude feedback to positively change their attitude on items on which they scored lower. The findings of this study indicate that the use of computer tailoring aimed at providing stage-matched advice has proven equally effective regardless of the variations in participant characteristics, although some adaptations are needed regarding the participant age, BMI, and intention.

Identification of moderators is a developing field in health-related behavioral sciences. A review among environmental intervention studies targeting energy balance-related behaviors among children and adolescents found that less than only one fifth of the studies they investigated conducted moderation analyses, with a possible publication bias not even taken into account [21]. The authors argued that despite being an exception, moderation analysis should become common practice in the field of energy balance-related behaviors to increase understanding of behavioral change [21]. In line with the conclusions of this review, we would like to urge subsequent intervention studies to conduct moderation analyses to identify certain subgroups of behavioral change in order to improve the effectiveness of future interventions.

The study is subject to some limitations. Firstly, the measurements of the moderators and PA behaviors relied on self-report. As a result, the responses could be biased by social desirability. Although self-reports may be less accurate than objective observations, self-administered questionnaires are the most commonly used method of assessing physical activity because they are relatively

inexpensive and easy to use in large-scale cohort or intervention studies. Especially, in tailored interventions that require quick tailored feedback to the activity level of specific behaviors, an objective measure might not be appropriate. However, validating the intervention effects with objective measurement data in the future would be recommendable. Secondly, the results may be influenced by the sample characteristics because of selection bias and response bias related to the sample characteristics or other unmeasured confounders. Therefore, generalization of the results might be biased by the initial response and selective dropout. Further, it must be noted that the randomization was not entirely successful since some differences in baseline characteristics were found (i.e., educational level, BMI, self-efficacy, walking, and cycling behavior). By including covariates into the regression analyses and analyzing the total dataset, including the missing data using multilevel analyses, we accounted for selective dropout as much as possible [40]. Thirdly, subgroup analysis could be seen as a form of multiple testing, increasing the chance for a type 1 error [41]. In a subgroup analysis, the probability of obtaining a false-positive result (type 1 error) is almost double (9.75% instead of the nominal 5%) [41]. By first pre-specifying our potential moderators based on previous research [36] and by following the guidelines for subgroup analysis provided by Fayers and King, we first examined the appropriateness of conducting a moderation analysis to minimize the chance of acquiring false-positive results. Last, the power calculation conducted to estimate the amount of required participants to establish an intervention effect was not based on the conduction of moderation analyses. Therefore, we set our p value at 0.10 as recommended [42].

Despite these limitations, the environmentally tailored intervention was found to be effective in changing total weekly minutes of PA behavior, leisure cycling, and sport compared with the no-intervention control condition and basic tailored intervention without environmental information. No significant intervention effects were found in the basic tailored intervention. The results assume that providing environmental information is an effective intervention strategy for increasing PA behavior among older adults, especially among certain at-risk subgroups, such as lower educated, overweight, or insufficiently active participants. In addition, participants with a higher age, lower BMI, and higher intention were found to be unresponsive to the interventions. These unresponsive subgroups should receive special attention in future intervention programs. Moderation analysis was perceived as a promising method for identifying meaningful subgroups. Future moderation analyses studies are needed to determine if these results are reproducible among other studies and confirm our results.

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